

Design an infrared radar training module

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Abstract— In this project we designed a type of close proximity infrared radar training module that can be used to detect any object close to the device by scanning with an angle of 180° and from a distance from 20cm to 150cm.

The main target of the project was to develop a low cost radar training module for students to have an idea about what radar is, to visualize the sensed data from the IR sensor to a radar screen, Sharp GP2Y0A02 series infrared distance sensor was used in the project. It will detect and measure anything within a 20-150cm range and it does this by triangulation method from where it emits a beam of IR and from when it receives it.

Basically a pulse of IR light is emitted by the emitter. This light travels out in the field of view and either hits an object or just keeps on going. In the case of no object, the light is never reflected and the reading shows no object. If the light reflects off an object, it returns to the detector and creates a triangle between the point of reflection, the emitter, and the detector.

We use the Arduino to control a servo motor that will rotate our IR sensor around 180 degrees. The Arduino will then send the value from the distance sensor along with the current angle of the servo motor to the serial port. The project also used the programming language 'Processing' to visualize the data received as a dynamic graph.

Although the main aim is to develop an IR radar training module, this infrared radar has other applications too. This can be used as a home security system by coupling it to an alarm. Also it can be coupled to an obstacle avoiding mobile robot platform in order to maneuver in any terrain. The most important feature in this radar is that it is a low cost radar.

Keywords—Infrared, Radar, Arduino, IR Sensor

I. INTRODUCTION

A. What is radar?

Radar is an object detection system which uses radio waves to determine the range, altitude, direction, or speed of objects. It can be used to detect aircrafts, ships, spacecraft, guided missiles, motor vehicles, weather formations, and terrain. The radar dish or antenna transmits

pulses of radio waves or microwaves which bounce off any object in their path. The object returns a tiny part of the wave's energy to a dish or antenna which is usually located at the same site as the transmitter. (radar)

Radar further permits the measurement of the instantaneous speed of such an object toward or away from the observing station in a simple and natural way. Today the radars are used in many fields such as air-defense systems, air traffic control systems, radar astronomy, antimissile systems, marine radars, aircraft anti-collision systems, ocean surveillance systems, outer space surveillance and flight control systems. Depending on the type, the radar can be classified as

- Primary Radar
- Secondary Radar
- Continuous Wave Radar (CW)
- Frequency Modulated Continuous Wave Radar (FMCW)
- Bistatic Radar
- Side looking Airborne Radar

When people use radar, they usually try to accomplish one of three things,

- Detect the presence of an object at a distance
- Detect the speed of an object
- Map something

All three of these activities can be accomplished using two things we are familiar with in our everyday life, i.e. echo and Doppler shift.

B. How radar works

The basic principle of operation of primary radar is simple. Radar measurement of range or distance is made possible because of the properties of radiated electromagnetic energy.

The following principles can be implemented in a radar system and allow the determination of the distance, and direction and the height of the reflecting objects.

1. Reflection of electromagnetic waves.

- Electromagnetic energy travels through air at a constant speed.
- Electromagnetic energy normally travels through space in a straight line.

The Radio Frequency (RF) energy is transmitted to and reflected from the reflecting object. A small portion of the reflected energy returns to the radar. This returned energy is called an echo. From that we can determine the direction and the distance of the target. (radar basics)

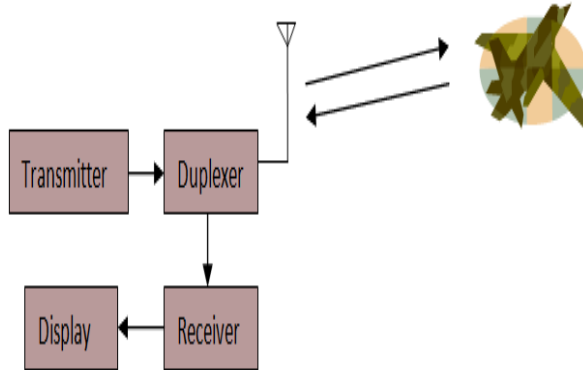


Fig 1. Radar basic structure

Infrared energy

Infrared (IR) light is electromagnetic radiation with longer wavelengths than those of visible light, extending from the nominal red edge of the visible spectrum at 700 nanometers (nm) to 1 mm. This range of wavelengths corresponds to a frequency range of approximately 430 THz down to 300 GHz and includes most of the thermal radiation emitted by objects near room temperature. Infrared light is emitted or absorbed by molecules when they change their rotational-vibrational movements. (infrared energy)

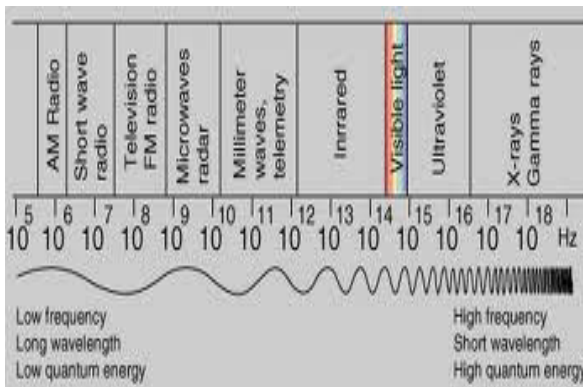


Fig 2. Electro Magnetic Spectrum

A. Telecommunication bands in the infrared

In optical communications, the part of the infrared spectrum that is used is divided into seven bands based on availability of light sources transmitting/absorbing materials (fibers) and detectors.

Band	Descriptor	Wavelength range
O band	Original	1260–1360 nm
E band	Extended	1360–1460 nm
S band	Short wavelength	1460–1530 nm
C band	Conventional	1530–1565 nm
L band	Long wavelength	1565–1625 nm
U band	Ultra long wavelength	1625–1675 nm

Table 1. Telecommunication bands in IR

II. INFRARED RADAR

This radar use infrared waves as a source. Here we use IR transmitter to direct IR waves to the target. The reflected IR energy is received by an IR receiver. Here we use SHARPGP2Y0A02 sensor as IR transmitter receiver module. From that sensor module we take analog voltage output proportional to distance it measures. We take that analog output and process it as distance value. This processing part is done through an Arduino Dumilinoe board.

Here our radar scanning mechanism is mechanical beam steering method and it is done by mechanically rotating the sensor module by using Servo motor. PWM output of the Arduino Dumilinoe board is supply 0 to 180degree rotation to the motor. Then Radar sensor module can scan foregrounds over 180 degrees. Through the Arduino Dumilinoe board serial port we are taking this distance value and the angle value at a 9600 baud rate. From the serial monitor we can see this angle value as 'X' and distance values as 'V'. The system has been constructed by using trial and error method because the values we got for the readings were inaccurate as the servo motor's speed increased. To overcome from that we reduce the speed of the servo motor in order to obtain a required level readings.

Then we make program to monitor this angle values and distance data as a radar screen. For that we used java based program called 'Processing'. This program can directly call to the Arduino Dumilinoe board and it can take data through its serial port. From this processing software we made interface to monitor the X vs V values which are taken from board, in a screen. In the radar screen we can see the angle values vs distance values represent in a polar form.

III. LITERATURE REVIEW

With the invention of the radar a new chapter began and it dramatically affected air and ground operations. In

1940, basic radar systems had a key effect on the Battle of Britain because it stretched the Royal Air Force's (RAF) ability to see across the English Channel (Keegan, 1990) The radar made great strides in development as systems became sufficiently small and it could be fixed on large aircrafts, which allowed RAF bombers to image the ground for accurate night bombing or day bombing (Barker, 1981) By the end of the war the Germans had developed radar systems for use on fighter aircrafts (Delve, 1995)

Because of the successiveness of radar it confirmed that this technology would be heavily developed to a great extent. To achieve the Military desires like making the radar lighter with better resolution, lower power consumption and effectiveness in bad weather conditions are the areas that should be worked on. . The story of radar-based systems since World War 2 geared to a heavy technology pull. However, despite the tremendous benefits offered by this new technology for military operations, radar had some serious limitations in comparison with human vision. These included low resolution, large size and power requirements. It is for this object that the world technological community turned to the development of other capabilities such as infrared technology is a great example.

The infrared which is part of the electromagnetic spectrum presents many advantages to the subject of radar. Since the infrared spectrum is just near to the visible spectrum, the concept for design and the imagery produced by infrared systems is relatively straightforward. The infrared systems pretend human vision to produce imagery that looks like a visual picture.

After the World War 2 the radar was a heavy impact to the electronic warfare. But the IR systems didn't have a great exposure. There were lots of theories based on IR but it couldn't work out for the real time applications. The only wartime infrared system in World War 2 was a sniper scope which allowed night time targeting at a range of 75 yards (Hudson, 1969)The Germans used IR searchlights and simple IR vision devices to conduct armor attacks at night, but these experiments were largely unsuccessful (Westrum R. , 1999). IR systems largely depended on technology development.

A small team of USAF at Naval Weapon Centre in China Lake developed an infrared guided missile, in which the pilot used the missile's IR seeker to lock on to the target. (Westrum R. , 1999) When the missile is fired it would guide on the infrared emissions of the enemy aircraft's jet engine, which required no further action from the pilot who could look for another target or escape enemy counter action.

The researches of IR achieved a great success at the later stages when USAF Western piloted F-15 or F-16 aircraft

has never been shot down in air to air combat (Hallion, 1999) A huge amount of credit goes to the air-to-air missiles guided by radar and IR sensors. Inthe 1980's when the Russians were dropping down on their Electronic and computational power their advanced radar systems became less effective. As a result the Soviets heavily relied on more reliable, easier to design, computationally simpler and tougher-to-jam IR systems, which surprised Western troops.

Since 1990, with the development of IR systems, USAF expressively improves the ability to develop accurate weapons and conduct many successive missions. So the IR holds a key role in modern Electronic Warfare.

Novotny and Ferrier have used infrared sensors to measure distances in a robot navigation application. (Ferrier., May 1999)

Similar approach has been used to in the work of Aytac and Barahan, where they use infrared sensors to differentiate and localize target primitives, also for use in robot navigation. (Barshan, October 2002).

The main key point is its low cost when comparing with other radar systems. So this has effected in more inexpensive weapons. The low cost of GPS receivers and microprocessor revolution also has effected for the low cost weapon systems.

In the present world IR is used for many home based applications.

- Home security systems
- Car locking systems
- In TV's, CD players, Stereo systems
- In computers (Mouse, Keyboard, Floppy disk drives)
- Navigation systems
- Toys

3 Sharp GP2Y0A02 series infrared distance sensor

In this project we have used the SHARP GP2Y0A02 series infrared distance sensor. This is a very powerful IR sensor for low range applications. The transmitter and the receiver are situated inside the sensor. Through the transmitter the IR waves are transmitted. The IR waves which are reflected by the objects are sensed by the receiver.



Fig 3. Sharp GP2Y0A02 sensor

It will detect and measure anything within a 20-150cm range and it does this by triangulation method from where it emits a beam of IR and from when it receives it.

When considering the features of this IR sensor it has less influence on the colors of reflected objects and their reflectivity due to optical triangle measuring method and also it doesn't need an external control circuit, as the output can be directly connected to a microcomputer.

A. Absolute Maximum Ratings

Parameter	Symbol	Rating	Unit
Supply Voltage	V_{cc}	-0.3 to 7	V
Output Voltage	V_{out}	-0.3 to V_{cc} 0.3	V
Operating Temperature	T_{opr}	-10 to 60	C
Storage Temperature	T_{sto}	-40 to 70	C

Table 2. Absolute maximum ratings

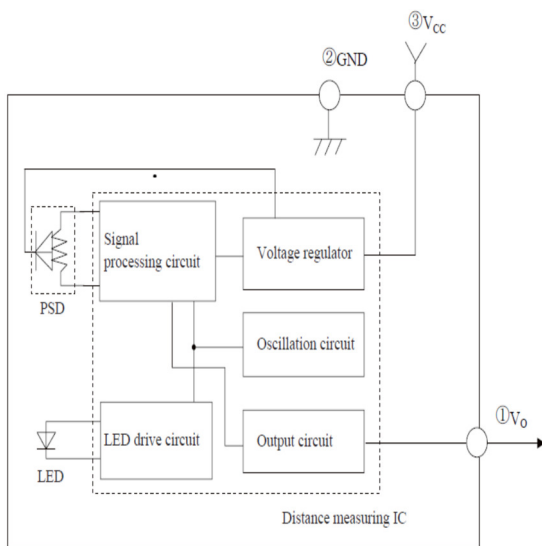


Fig 4. Internal block diagram of sensor

B. How the sensor works

This sensor uses triangulation and a small linear CCD array to compute the distance and/or presence of objects in the field of view. The basic idea is this: a pulse of IR light is emitted by the emitter. This light travels out in the field of view and either hits an object or just keeps on going. In the case of no object, the light is never reflected and the reading shows no object. If the light reflects off an object, it returns to the detector and creates a triangle between the point of reflection, the emitter, and the detector.

The angles in this triangle vary based on the distance to the object. The receiver portion of these new detectors is actually a precision lens that transmits the reflected light onto various portions of the enclosed linear CCD array

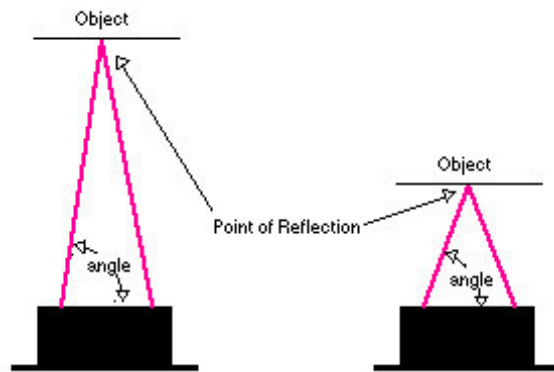


Fig 5. Different Angles with Different Distances

based on the angle of the triangle described above. The CCD array can then determine what angle the reflected light came back at and therefore, it can calculate the distance to the object.

This new method of ranging is almost immune to interference from ambient light and offers amazing indifference to the color of object being detected.

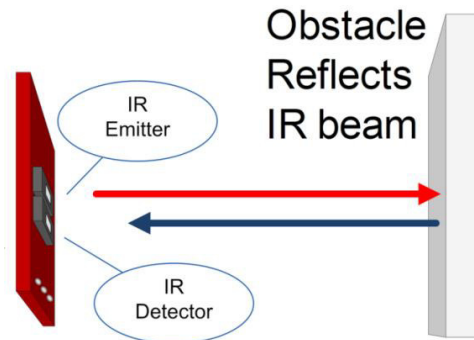


Fig 6. Reflection of IR beam

C. Working Principle of the IR Radar

When looking at the figure we can identify that greater the voltage the shorter the distance. So to measure distance the voltage change as the distance change should be measured.

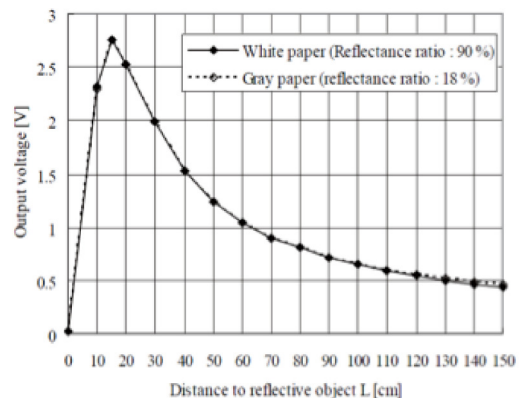


Fig. 7 Analog output voltage vs. Distance to reflective object

To do this the analog pins on the Arduino board should be used. Because the reading directly is from the sensor so the digital value of the Arduino which gives from the analog to digital converter should be converted. The analog pins convert whatever arbitrary analog value supplied to a byte value which is between 0 and 1023 (1024 variations)

Looking at the graph above, this converted value is of no use to us so we need to convert this value back to the true analog value. The voltage ratings of the power supply is taken and divided by 1024 to give us a value per step. So for instance:

$$5v/1024 = 0.0048828125$$

This value is multiplied by what the sensor sends back to get our voltage reading. The next stage is to work out an equation from the graph on the data sheet to get the theoretical distance from the voltage reading, when looking at the graph between 20 and 150cm we can see that it's exponential.

To get our distance on the graph our team came up with the following equation:

$$1/\text{Volts} * 65$$

65 are taken by the distance on the graph and dividing that by 1/Volts. So what to multiply is known with the voltage results by to get the distance. This is fine if there is only one value to read or if this is a linear graph, in that the change in voltage was always the same amount of distance.

For the exponential change the value should be changed now into an exponent. So our formula for distance from voltage reading is now something like:

$$\text{Distance} = (\text{Volts}^x) * 65.$$

Since the graph is a decaying exponential the value of x will be a fraction, to write this as an exponent we have to use a minus number e.g. -1. The exponent -1 is the equivalent of the fraction 1/2 which is 0.5 as a decimal.

Now through trial and error we programmed this into the Arduino and changed the exponent until the readings became accurate, It started at -1 and by co-incidence the next value we tried were -1.1 which is 11/10 as a fraction, 0.65 as a decimal and oddly enough 1/100th of our distance ration, 65

In Arduino the code for the equation is:

```
float volts= analog Read (IRpin)* 0.0048828125
```

```
float distance = 65*pow(volts, -1.10);
```

Again, read the analog pin and apply the above logic, printing the value to the serial port. Below is the Arduino coding to calculate the distance.

```
intIRpin = 1; // analog pin for reading the IR sensor
```

```
void setup(){Serial begin(9600); //start the serial port}
```

```
void loop(){float volts = analog Read(IRpin)*0.0048828125; // value from sensor * (5/1024)
```

```
float distance = 65*pow(volts, -1.10); // worked out from graph 65 = theoretical distance / (1/Volts)S delay(20); // wait time.}
```

The measuring is spot on, though of course the objects are closer than 20cm and are further than 150cm then the measurements will be grossly inaccurate as this is outside of the sensors environment.

D. Servo Motor

A servo motor is a brushless dc motor with a digital decoder which is a position sensing device. It is a closed loop servomechanism which uses the position feedback to control its final motion and position. For our project the three-wire DC servo motor is used and they are often used for controlling surfaces on model airplanes. A three-wire DC servo motor includes a DC motor, a gear train, a potentiometer for position feedback, and an integrated circuit for position control. Of the three wires which run from the motor casing, one is for power, one is for ground, and one is a control input where a pulse-width signals to what position the motor should servo. As long as the coded signal exists on the input line, the servo will maintain the angular position of the shaft. As the coded signal changes, the angular position of the shaft changes.

To rotate the servo from left to right, then right to left and for every degree of movement take a series of readings and send them to the serial port. An average reading value for consistency is to be produced.

The sensor rotates using a for loop to count to 180 and for each iteration the servo is moved by +1 or -1 depending on which way it is going. During this loop another FOR loop to count to 10/num Readings and for each iteration measured distance added to the total and after 10 readings we get our average by dividing the total by the number of readings. Then reset the total and the counter to start again for the next servo position. Finally before finishing the FOR loop for the servo the servo position and average reading to the serial port each is symbolized by a preceding character for us to later use to identify the values when reading the serial port in Processing. The last line is using println command which will start a new line for the next set of values – each reading has its own line in the serial buffer making it much easier to get our values back out.

E. Processing

Processing is a tool and Integrated Development Environment (IDE) that lets you to program and code

graphics and animation. The processing is open source software. The best part is it works hand in hand with Arduino in the same C/C++ style of code. The processing lets the data taken from the Arduino and whatever's plugged into it and then visualize it on screen, e.g. like a radar screen. So in this project the radar interface is made by the Processing software.

The below is the processing code for Radar Screen Visualisation for Sharp GP2Y0A02 series infrared distance sensor. It Maps out an area of what the GP2Y0A02 sees from a top down view. It takes and displays 2 readings, one left to right and one right to left. It displays an average of the 2 readings and also displays motion alert if there is a large difference between the 2 values.

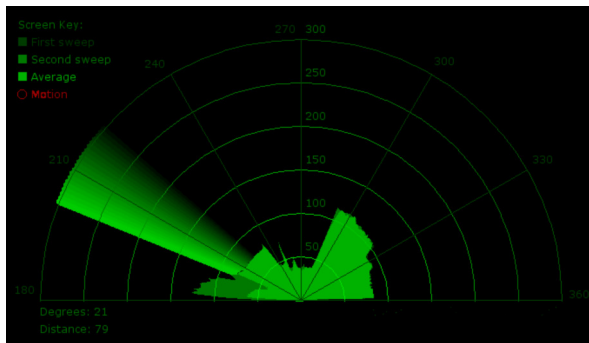


Fig 8. Processing sketch of radar screen

The above diagram is the radar screen sketched by using processing software which visualizes the sensed objects. Through this radar screen the distance to the object and the current angle to the object can be identified.

LIMITATIONS

1. The module cannot go higher distances due to sensor limitations and power limitations.
2. Low scanning speed (limitation of motor and sensitivity of sensor)
3. Cannot specify the type of target (it will only give angle and distance data)
4. Cannot measure the speeds of target (due to low speed and it does not sense the Doppler shift)
5. It takes only 2d scans and not 3d scans. (Because electronic steering is not possible and with mechanical steering we need two sensor modules when azimuth and elevation are scanned.)

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